Next Generation Air Transportation System
Joint Planning and Development Office

# Transforming the Air Traffic Management System – Why is it so Hard?


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# Report Documentation Page

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# Outline

- The Equity Concept
- Introduction to NextGen
- System Complexity and its Implications
- Trajectory-Based Operations
  - The TBO Concept
  - An Example: In-Trail Procedures
  - Another Example: Performance-Based Navigation
- Unmanned Aircraft Systems Integration

# The Equity Concept

Chocolate Cake Problem: How can I distribute this cake equitably among each of the students sitting in this room?

Reference: http://www2.edc.org/womensequity/edequity/hypermail/1432.html

# Means of Cake Distribution

- We could all get equal sized pieces of cake. But if some people don't want any cake that will make the pieces for everyone else artificially small.
- I could give everyone a fork and have you fight for your share. That could cause a mess and someone could be injured in the process.
- Perhaps we could each have an equal chance at getting a piece of cake by using a lottery system with the winner receiving the whole cake. That would mean most of you would be out of luck and someone is stuck with a whole cake.
- People could testify to their need for a piece of cake, and the most convincing get a piece. How will I decide who is most convincing?

# Aviation Stakeholders

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# NextGen Turns 10!

# NextGen Turns 10!



FAA's NextGen

NextGEN

# Partners in the Next Generation Air Transportation System

*Joint Planning and Development Office*

# The JPDO Collaborative Methodology

- Stakeholder engagement
- Define roles and responsibilities for strategy execution
- Establishment of compatible standards, policies and procedures
- Monitor and report on multi-agency progress through Senior Policy Committee

Results are National approaches to complex NextGen related issues and reduced duplicative efforts leading to cost savings.

# How do we Accomplish our Goals?

- The JPDO fosters a collaborative approach
  - Provides a “future” focus
  - Maintains a “big picture” perspective
  - Conducts a variety of analyses to address priorities
- The assessments include:
  - Program management and integration
  - Cost, benefit and risk assessment
  - Policy analysis
  - Interagency data exchange definition
  - Public/private partnership – NextGen Institute
  - Maintaining and supporting the National integrated plan

# 2025 Concept

## *Operating Principles*

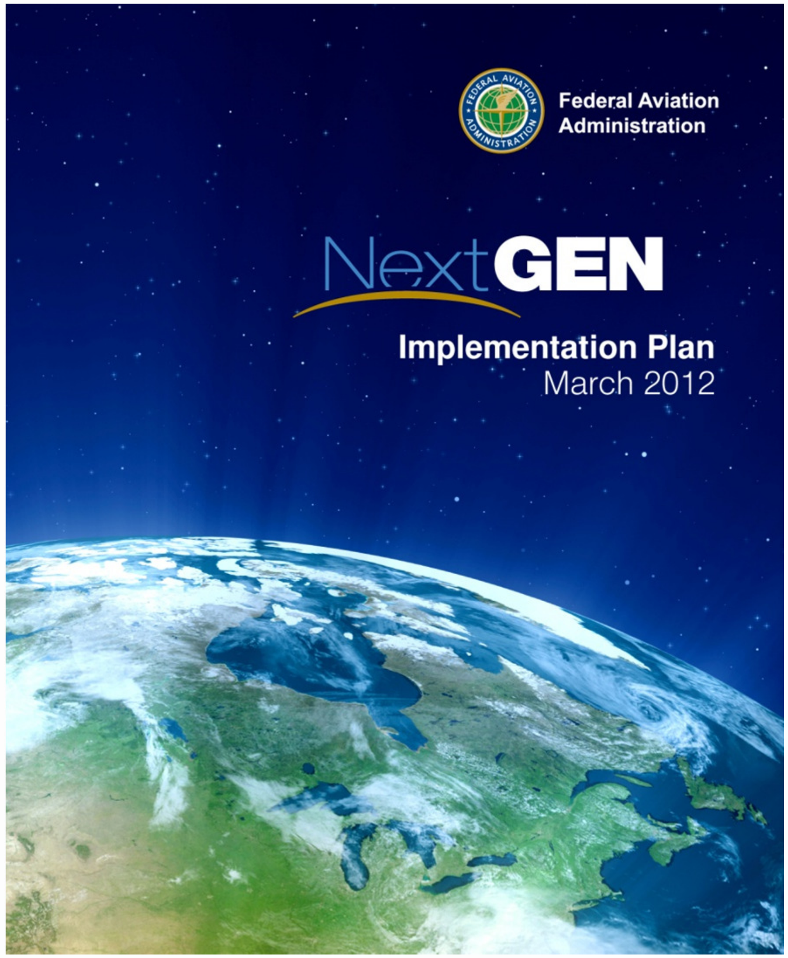
- "It's about the users…"
- System-wide transformation
- Prognostic approach to safety assessment
- Globally harmonized
- Environmentally compatible to enable continued growth

## *Key Capabilities*

- Net-Enabled Information Access
- Performance-Based Services
- Weather-Assimilated Decision Making
- Layered, Adaptive Security
- Position, Navigation and Timing Services
- Trajectory-Based Aircraft Operations
- "Equivalent Visual" Operations
- "Super Density" Operations


Version 2.0 (13 June, 2007) at:
**http://www.jpdo.gov**

# FAA’s NextGen Implementation Plan




For more information see: http://www.faa.gov/nextgen

# Executable NextGen Architectures

Lowest Performance, Automation & Risk

JPDO NextGen Enterprise Architecture

Estimated FAA Segment β

JPDO Target 2025

| | | |
|---|---|---|
| NG-1 | Operational today, but not nationally. Integrated national deployment underway | Planning covered by RTCA Task Force 5 and being implemented for near and mid-term |
| NG-2 | Incremental improvements over NG-1 with better information, weather, and flight planning capabilities | |
| NG-3 | **Change in operations, but same roles and responsibilities** | **Most Likely NG performance level in 2025 based on current progress and key decision making/policy needed** |
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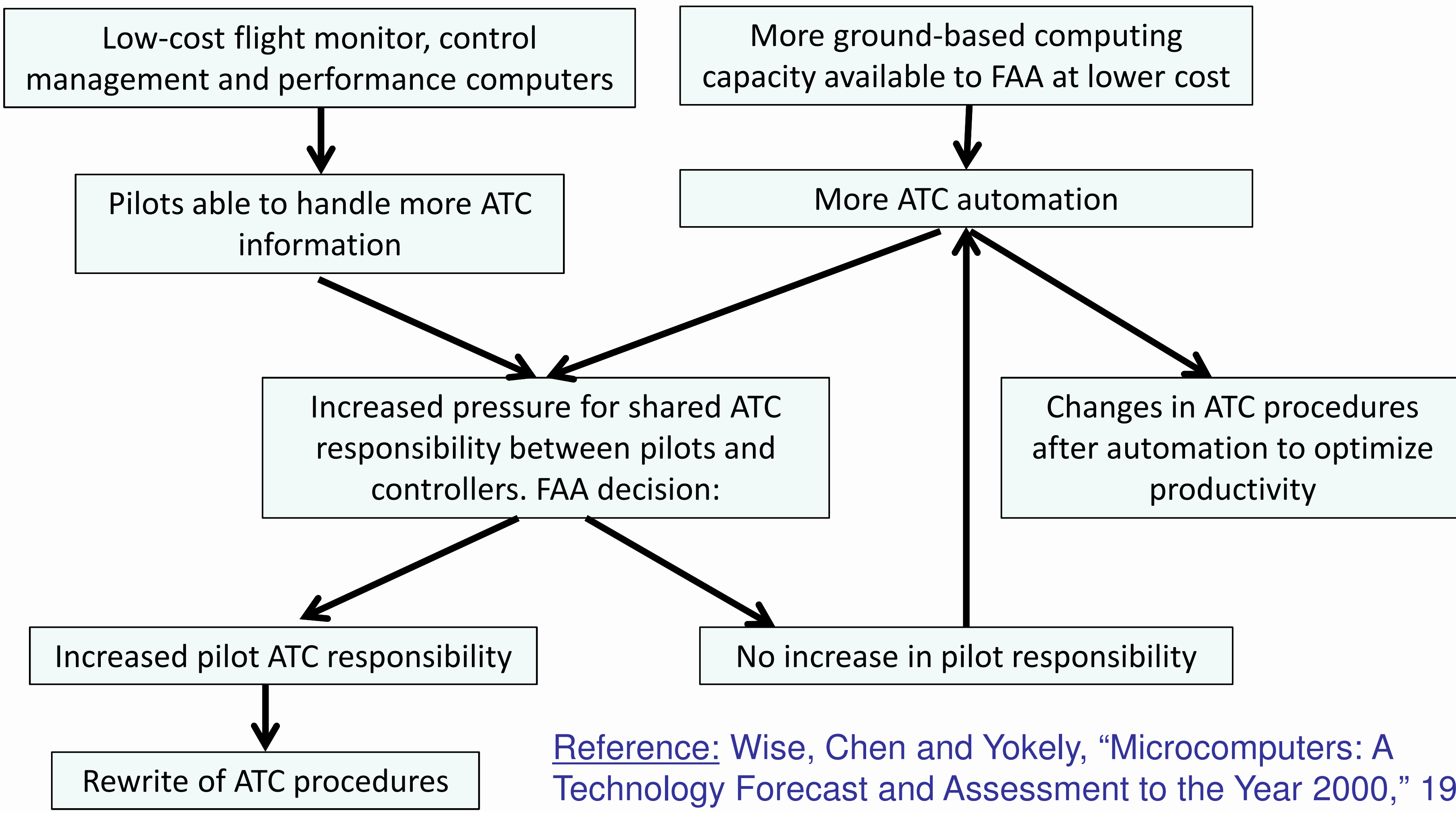
| NG-5 | Managing the NAS via 4-DT Trajectories. Full UAS file & fly capability. | NG-5 contains high implementation risks for the FAA in 2025 and NG 6 contains high R&D risks for the research community. NG-5 & 6 are probably achievable after 2025 at our current development and policy rates |
| NG-6 | Automated Separation Management | |

Highest Performance, Automation & Risk

# Microcomputer Technology Trends




Reference: Wise, Chen and Yokely, “Microcomputers: A Technology Forecast and Assessment to the Year 2000,” 1980

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# Definition

Wikipedia defines a complex system as:

"a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts."

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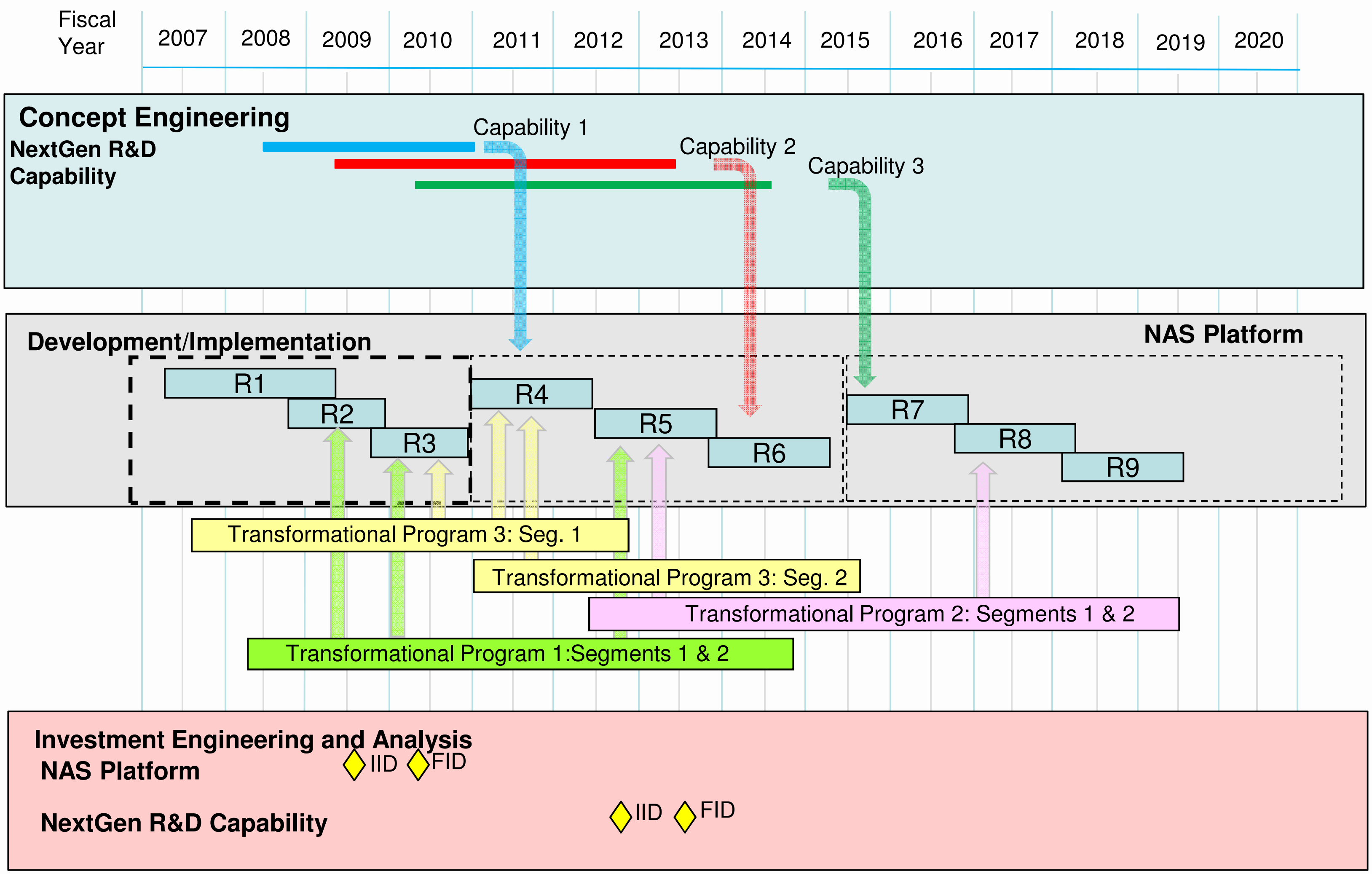
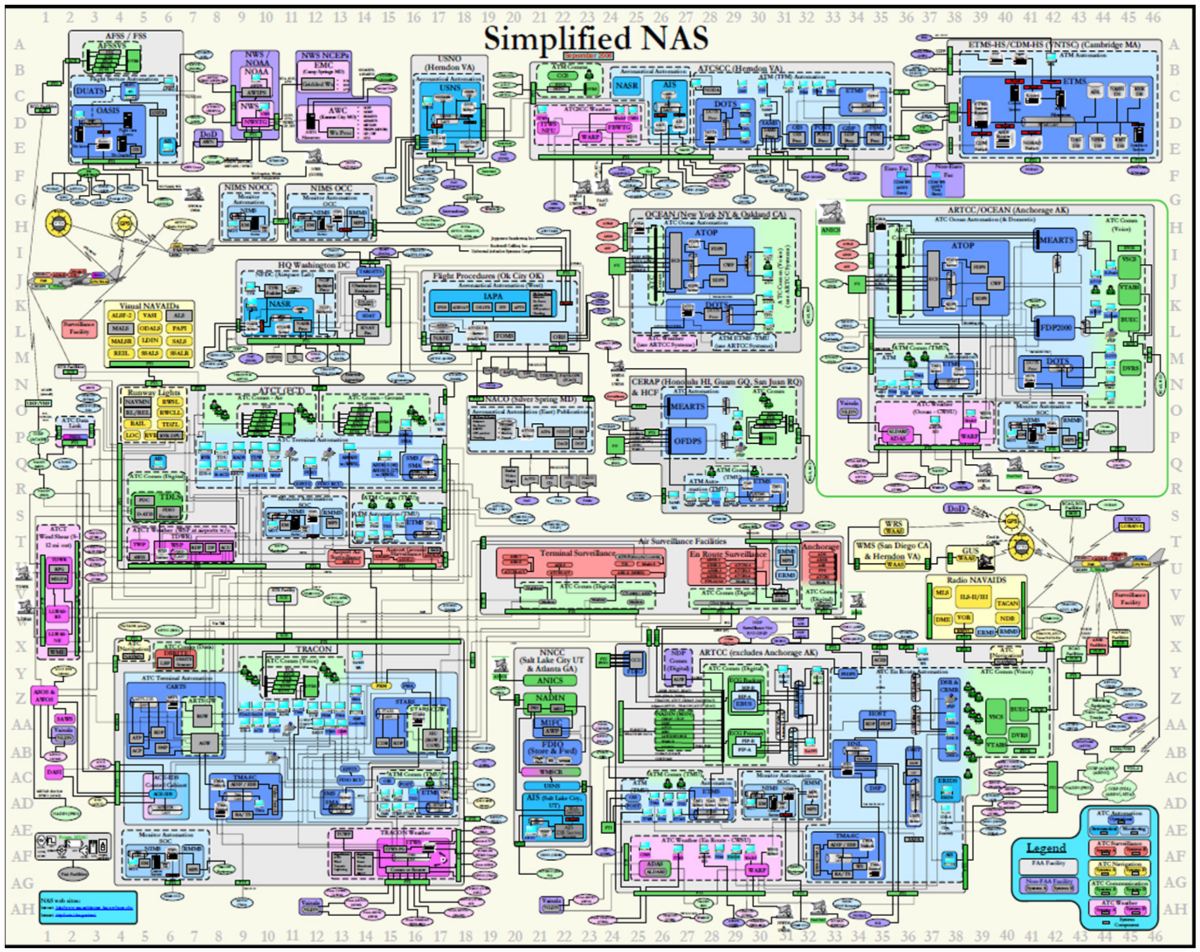
# Notional System Integration



# Complex Differs From Complicated



# Resilience to Different Futures

- This complex system must be resilient to many perturbations and failures
  - Transformation to NextGen will span more than 20 years
  - Aircraft that fly in the system have 20-30 year life spans
- A real life example: the DARPA internet in the 1980s

# F-22 Raptor

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# Evolution of ATC/ATM

**_Past_**

Procedural Separation

_Estimate_ current and future aircraft positions

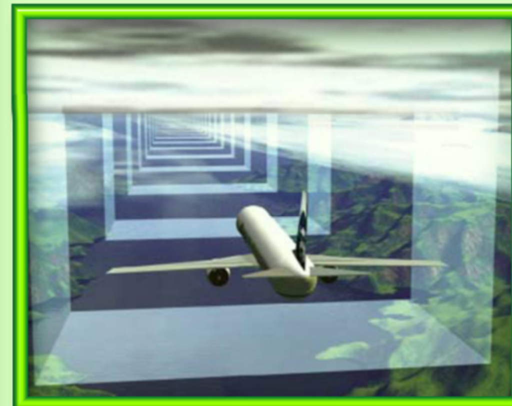
**_Present_**

Radar Separation

_Know_ current and _estimate_ future aircraft position

**_Future_**

4-D Trajectory Separation



_Know_ current and _know_ future positions

# TBO Concept Overview

- TBO represents a real paradigm shift in how we do air traffic management
- A generation beyond what FAA and RTCA call Trajectory Operations and “TBO” as used by SESAR
- The underpinnings of TBO are:
  - Trajectory planning
  - Trajectory negotiation
  - Execution of negotiated 4D trajectory from gate to gate
  - Trajectory replanning and re-negotiation to deal with new ATM system constraints or changes in user desires
- Today’s sectors and route structure may disappear

# TBO Concept Overview (cont'd)

- Pilots, controllers, FAA flow managers, and Operations Centers may see their roles change.
- They will interact with each other and with their respective automation systems in new ways.
- A 2012 JPDO study examined how future roles for Operations Centers are critical to improving aviation safety.
  - TBO will allow operations centers to negotiate a flight's trajectory before it takes off, helping operators meet the response to expected increases in demand.
  - It will also allow operators to negotiate optimal flight paths for individual flights based on optimization of their entire network.

# TBO Concept Overview (cont'd)

- TBO requires a truly net-centric system.
  - Timely, common information will be available to all (humans and machines) to help them make their decisions.
  - While any change in the approach to separation represents a cultural shift, the increased collaboration through net-centricity to improve common situational awareness will increase predictability and reduce variability.
- This concept is about choices, negotiations, and precise navigation.
- BUT -- there are still a lot of unknowns in TBO that present a fertile area for research

# Some TBO Research Questions

- How resilient is the plan when the system is interrupted by weather, airport acceptance rates change, or unexpected aircraft enter the zone?
- Should aircraft separation be ground-based? If not, what is the best role for the pilot and cockpit automation?
- When does a trajectory need re-negotiated? How often and for what cause?
- How is the prioritization done when scarce resources must be allocated? (Remember how hard it was to distribute the chocolate cake!)

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# ADS-B In-Trail Procedures

*Enabling Climbs, Saving Fuel*

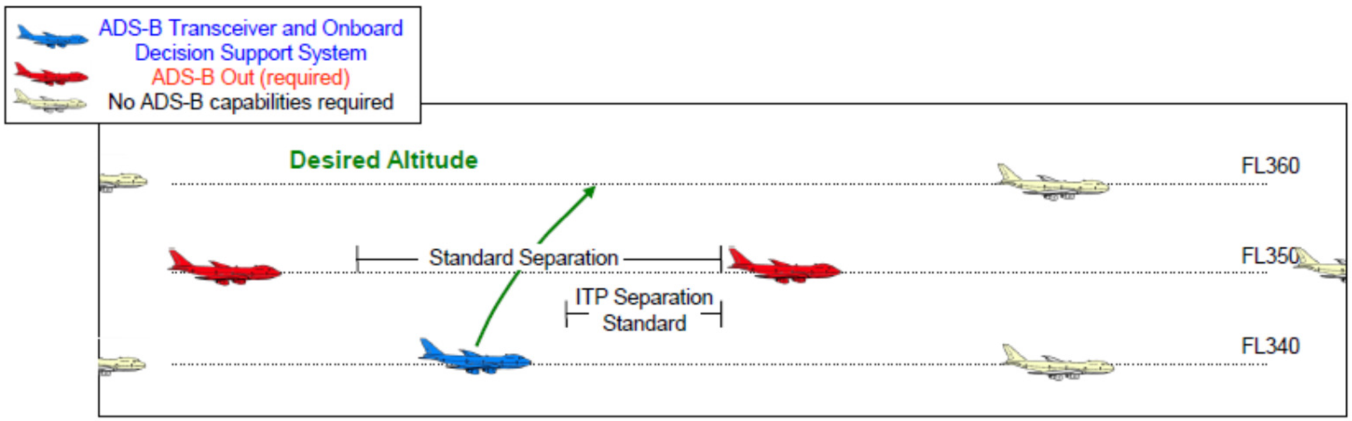
## From Concept to Flight


AIAA Aviation Technology, Integration, and Operations Conference
Indianapolis, Indiana
September 17-19, 2012


Kenneth M. Jones
NASA Langley Research Center

# Enabling Altitude Changes

## Motivation for ADS-B In-Trail Procedures



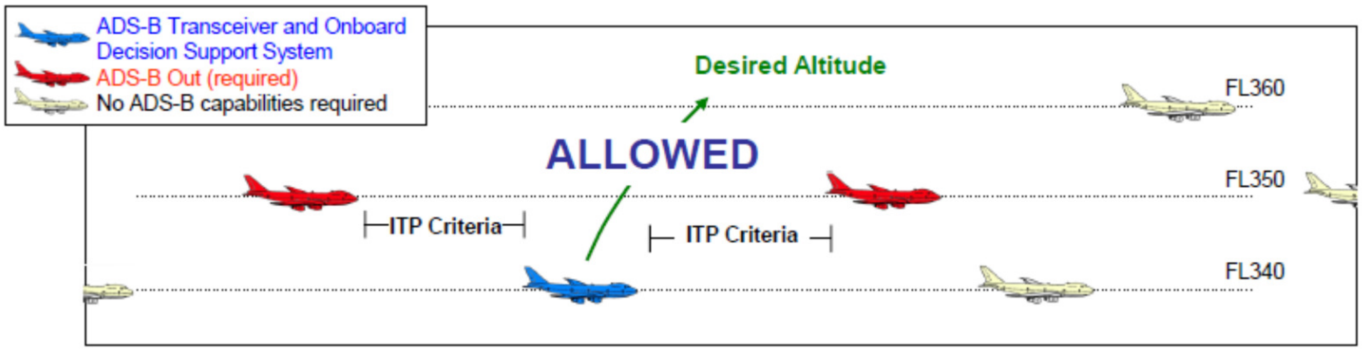

**NEED → CHALLENGE = OPPORTUNITIES**

- Altitude Changes required for better fuel economy, winds, and ride quality
- The combination of locally dense traffic and large separation minima limits altitude changes
- Use airborne ADS-B applications to enable altitude changes otherwise blocked by conventional operations

# Steps to Execute

## ADS-B In-Trail Procedures
*Sequence*

### ADS-B ITP Climb




### Pilot Responsibility

Step 1: Pilot verifies ITP criteria

- ITP distance is greater than 15 NM
- Ground speed difference < 20 kts if 15 NM - 20 NM from reference aircraft or <30 kts if greater then 20 NM

Step 2: Pilot requests ITP climb from ATC

Step 5: Pilot revalidates ITP criteria

Step 6: Executes maneuver

### Controller Responsibility

Step 3: Controller verifies:

- Altitude requested is available
- Closing Mach number difference between aircraft requesting ITP and reference aircraft $\leq$ 0.06

Step 4: Controller grants ITP climb

# Why do this Procedure?

- This is a straightforward procedure that enables aircraft to **save fuel** by flying at optimal altitudes and speed.
  - The certainty that less fuel will be used allows airlines to increase payload on an aircraft. Thus, the **airlines benefit**.
  - It also moves ADS-B In ahead with an application that gives those who choose to equip immediate benefits. The **FAA also benefits** with more ADS-B adopters.
- Given a simple algorithm that saves fuel and has benefits for airlines and air traffic control, why has implementation taken years?

# From Lab to Revenue Demonstration

## ADS-B In-Trail Procedures Maturity (~2008)

- **Concept Development (2004)**
- **Evaluation (2005-2007)**
  - **2005 - 2007** Batch simulations to evaluate ITP climb opportunities and efficiency gains
  - **2006** Experimental HITL evaluation of ITP and cockpit decision support tools: pilot perspective
  - **2007** Experimental HITL evaluation of ITP operations: controller perspective

**ITP Prototype Display (2006)**
in NASA LaRC's Air Traffic Operations Lab

- **Standards**
  - RTCA DO-312: ITP system level avionics standard (2008)
  - ICAO Separation and Airspace Safety Panel (SASP): ADS-B ITP Circular (panel approved ITP separation standard, 2009)
- **Next step – move from simulation to revenue service**
- **Transfer technology to the FAA**
  - FAA SBS had the mission and resources to implement this in revenue service

# Working toward Flight Approvals

## ADS-B In-Trail Procedures

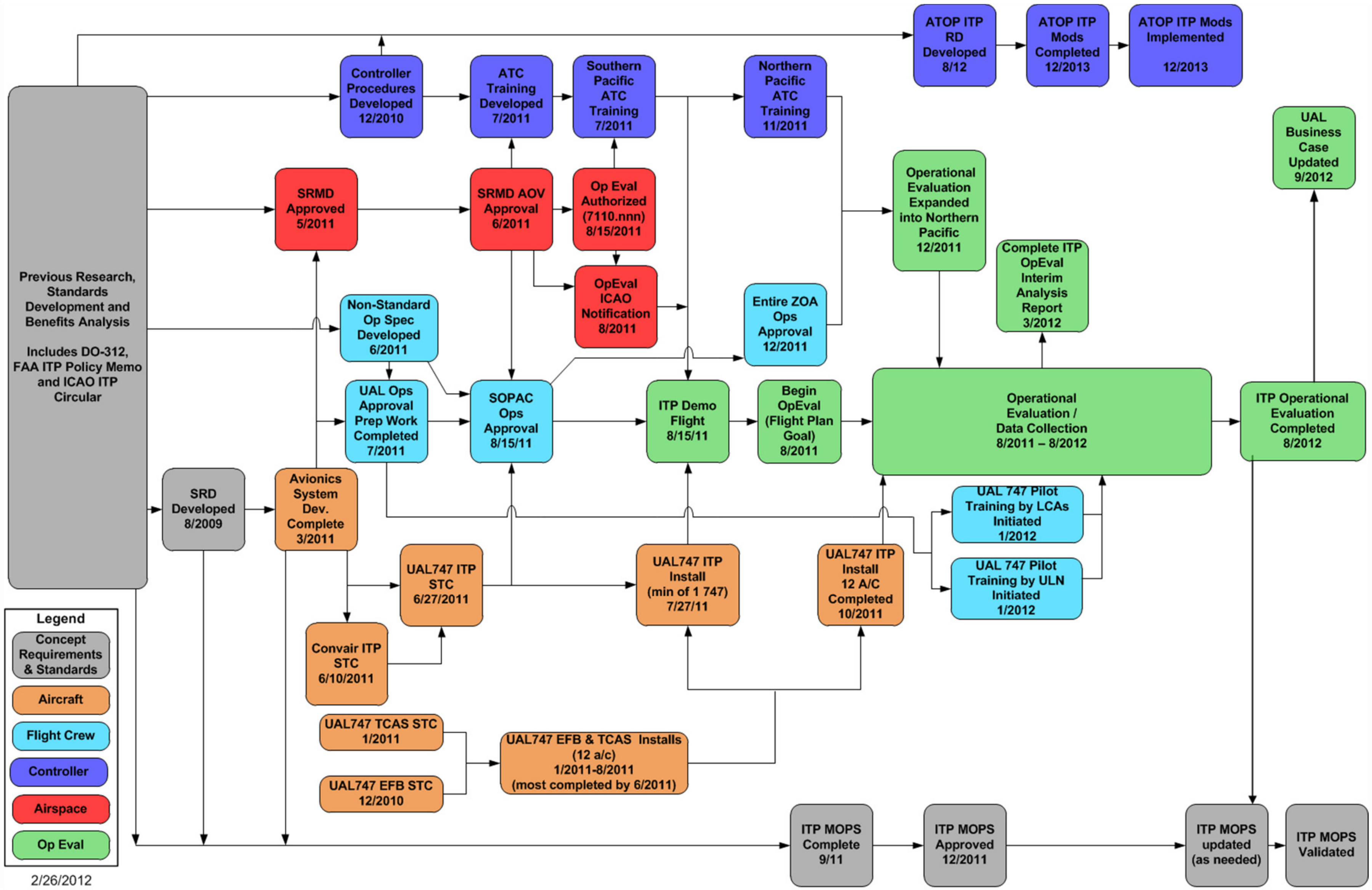
*Operational Evaluation Partnership Agreements*


- **Partnership**
  - FAA and United Airlines agreement signed in April 2009
    - Additional partners include Honeywell and Goodrich
- **Scope**
  - Retrofit 12 UAL 747-400 aircraft with certified ITP systems
  - Gather data on use of systems in SOPAC for a year starting in 2011

Honeywell GOODRICH

- **Outcomes**
  - Validate economic benefits of ADS-B ITP
  - Validate operational performance of ADS-B ITP
- **ASPIRE Agreement Partners**
  - Air Services Australia
  - Airways Corp. New Zealand

# In-Trail Procedures Key Activities



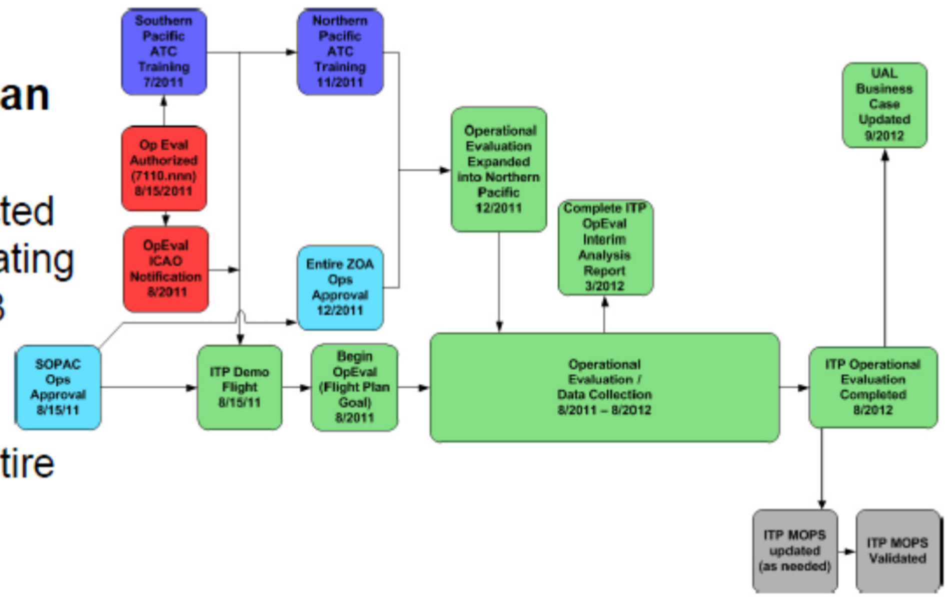
# Evaluation Equipment

- Equipment was kept as simple as possible
- Avionics were not modified
  - Electronic flight bag developed by Honeywell
  - Certification was difficult since this was new
- FAA's oceanic system (ATOP) was not modified
  - Controllers used an operational checklist

# Data Collection to Validate Safety, Operational Performance and Economic Benefit

## Operational Evaluation

- **Operational Evaluation began on August 15, 2011**
  - Demonstration flight conducted using two United 747s operating in revenue service; UAL 863 and UAL 869 had qualified aircraft and flight crews
  - Expanded to encompass entire ZOA FIR December 2011




- **Op Eval will take place for at least a two year period**
  - Data will be collected and analyzed
  - Data used to validate safety assumptions and will gather data on operational performance and economic benefits

# Stakeholders who Needed to Agree

- Air Navigation Service Providers:  FAA and Air Services Australia
- Standards organizations:  ICAO and RTCA
- Manufacturers: Honeywell
- Airlines:  United
- Controllers
- Pilots

# Another Example: Performance-Based Navigation

- Researcher – it's a straightforward math model and simulation flights.
- System engineering – it's testing and integrating the math model within complicated software infrastructure.
- Controllers -- it's all about predictability.
  - How do you deal with different performance of different aircraft and equipage in the same airspace. Integration into busy airspace is even harder.
- Airport operator -- it depends on the community view.
  - Particular airports or metroplex areas must be considered to select locations for implementation. Are they highly engaged with the community?
  - How receptive will the community be to the precise tracks which coalesce all the noise in a certain place?
- Flight operators -- it's all about the business case.
  - Does the idea have economic benefit?
  - That case differs for general aviation, business and commercial carriers.
  - The benefit of the procedure is mostly external to the FAA but these operators have different views.

# Another Example: Performance-Based Navigation

- In some cases, significant equipage is required to give users the benefits.
  - This leads to the equipage “chicken and egg” problem. When should I equip?
  - Early adopters sometimes don’t get the best return on investments.
- The FAA investment needs a different benefit than the operators.
  - For example, greener skies reduces complexity, hence mistakes or workload for controllers.
- There are also trades to be made.
  - Fewer track miles versus getting from the surface to altitude quicker?
  - System view or certain aircraft view only?
  - So you have to decide "which benefits"?
- Weather is always the wildcard.
- Politics and environment have a role too.

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# New Frontiers for Aviation

- UAS challenge the airspace system with new flight paradigms:
  - Small, medium, and large aircraft
  - Varying performance
- Pilot and controller roles must be considered for the widely mixed fleet:
  - Remote pilots and autonomous aircraft
  - Training, qualification, and safety standards




# NextGen Then and Now:
## From VLJ to Quadrocopter


JPDO analyzed whether the NAS was scalable to meet traffic patterns of Very Light Jets (VLJ) such as this Eclipse 500
http://en.wikipedia.org/wiki/Very_light_jet

"Flying Robots Deliver Tacos to your Location. Our unmanned delivery agents are fast and work tirelessly."
http://www.tacocopter.com

# Executable NextGen Architectures

Lowest Performance, Automation & Risk

JPDO NextGen Enterprise Architecture

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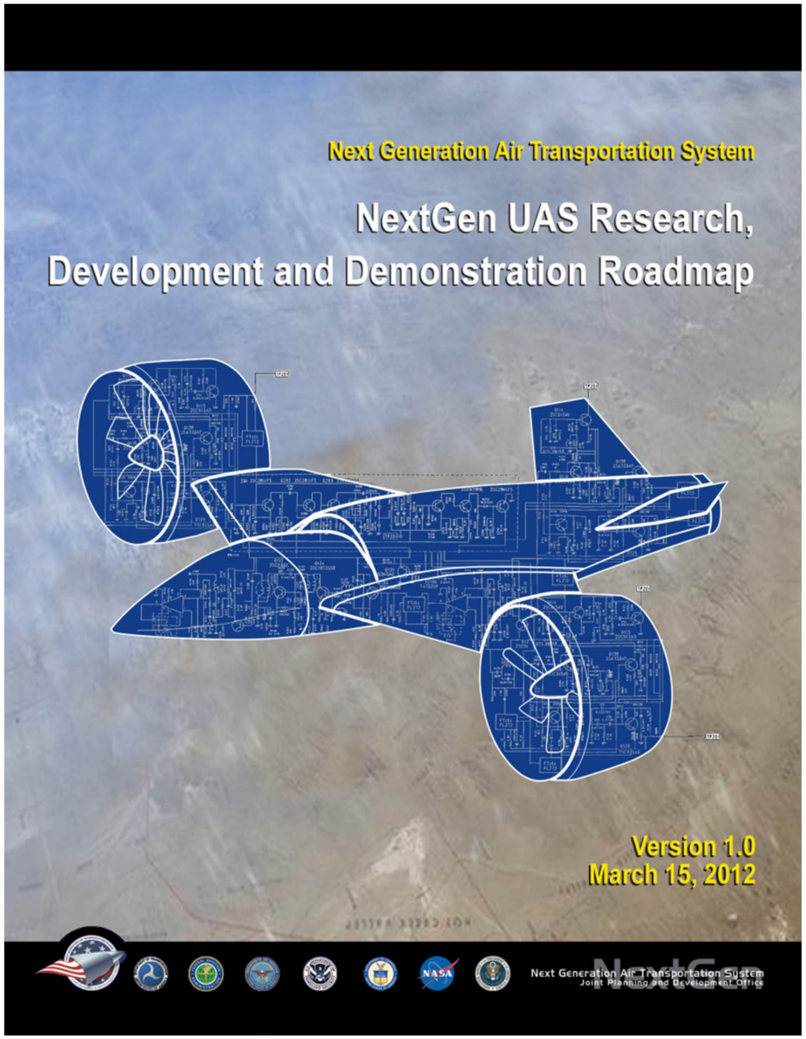
Highest Performance, Automation & Risk

# UAS Research Roadmap




- Technical tracks
  - Communications
  - Airspace operations
  - Unmanned aircraft
  - Human systems integration
- Major challenges
  - Sense and avoid capability
  - Dedicated protected spectrum for control links
  - Unmanned aircraft and cockpit certification standards

# Mapped Critical R&D Challenges, Needs & Goals

| R&D Challenges | FAA Needs: Develop and validate UAS performance requirements for normal and abnormal operations | Resolve UAS and ATC interoperability issues during normal and abnormal operations | Provide robust failure modes and recovery operations | Validate NextGen concepts (e.g., "4D trajectory based") using UAS as testbed. | Develop adequate safety case of UAS NAS integration | Develop required policies, standards and certification guidance material | Develop concepts for the wide-spread integration of UAS into the future NAS |
|---|---|---|---|---|---|---|---|
| *3. Unmanned Aircraft* | | | | | | | |
| 3.1 State Awareness and Real Time Mission Management | X | X | X | | X | X | |
| 3.2 Airframe Certification | | | X | | X | X | |
| 3.3 Precise Location and Navigation | X | | | | X | | |
| 3.4 UAS Avionics and Control Systems Certification | X | | X | | X | X | |
| *4. Human Systems Integration* | | | | | | | |
| 4.1 Display of Traffic/Airspace Information | X | | | X | X | X | X |
| 4,2 Effective Human-Automation Interaction | X | X | X | X | X | X | X |
| 4.3 Pilot-Centric GCS | X | | | X | X | X | X |
| 4.4 Definition of Roles and Responsibilities | X | X | | | X | | X |
| 4.5 Predictability and Contingency Management | X | X | X | | X | | |
| 4.6 System-Level Issues | | X | | | X | | X |
| 4.7 NextGen Airspace Users and Providers – Qualification and Training | | | | | X | X | |
| 4.8 Support for Future/ Enhance Capability of UAS | | | | | X | | X |

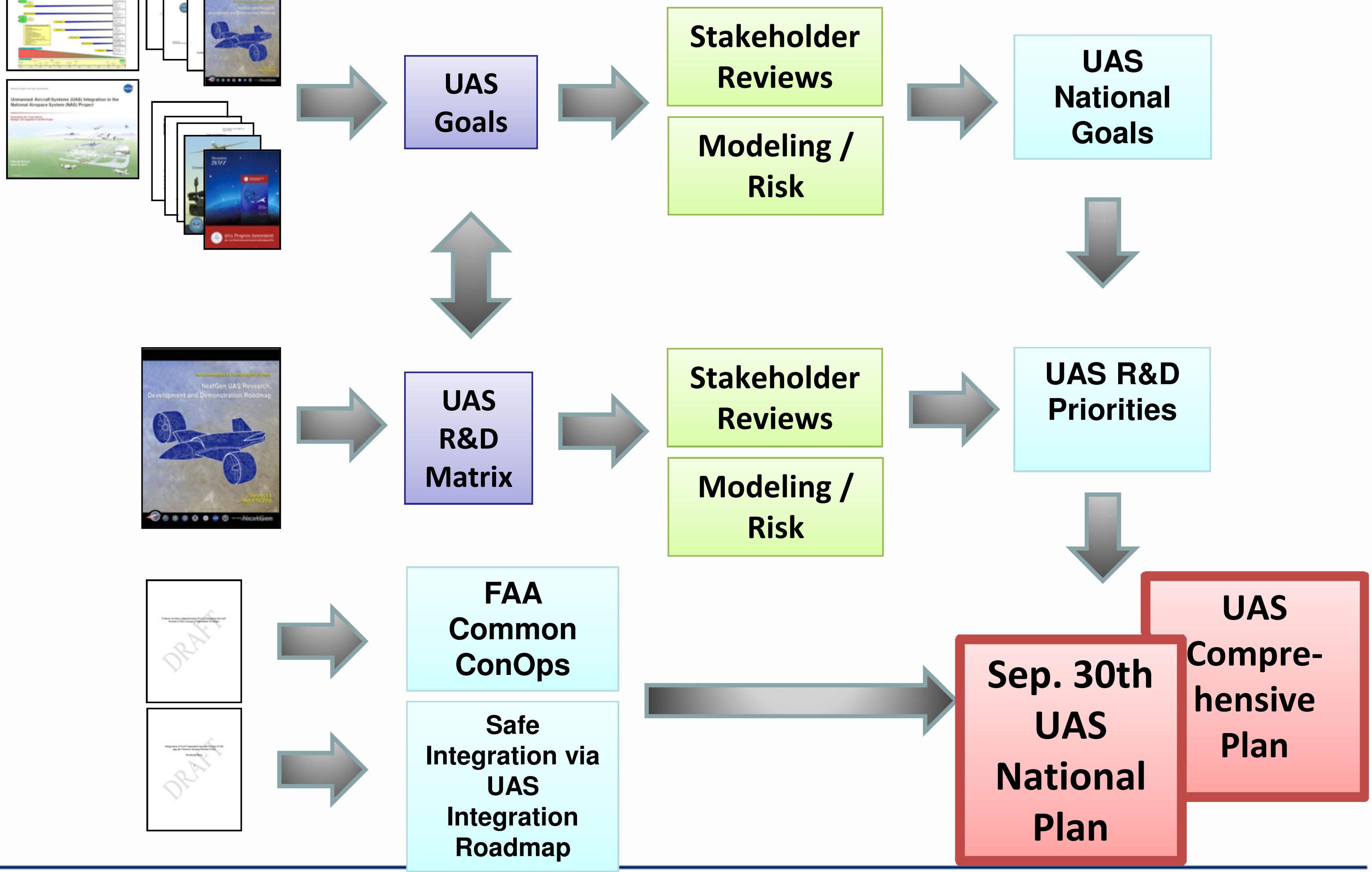
| CHALLENGES | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Communications | | | | | | | | | | | | |
| 1.1 Impact of UAS Operations on NAS Communication Systems | | Δ Goal 1 TBD | | | | Δ Goal 2 TBD | | | | | | |
| 1.2 Ensure Availability of UAS Control Frequency Spectrum | | Δ Goal 1 TBD | | | | Δ Goal 2 TBD | | | | | | |
| 1.3 Develop and Validate UAS Control Communication System Performance Requirements | | | | Δ Goals 1 & 2 TBD | | Δ Goal 2 TBD | | | | | | |
| 1.4 Ensure Security of Safety Critical Communications with UAS | | Δ Goal 1 TBD | | | Δ Goal 2 TBD | | | | | | | |
| 1.5 Design and Develop UAS Control Datalink for Allocated UAS Frequency Spectrum Bands | Goals 1 & 2 TBD | | | | | | | | | | | |
| 2. Airspace Operations | | | | | | | | | | | | |
| 2.1 Develop Integrated Separation Concepts | | Δ Goals 1 & 2 | | | Δ Goal 3 | | | | | | | |
| 2.2 Develop Airspace Integration Safety Case/Assessment | | Δ Goals 1 & 2 | | Δ Goal 3 (2014+) | | | | | | | | |
| 2.3 Develop Sense and Avoid (SAA) Sensors and Fusion | Δ Goal 1 | Δ Goal 2* | Δ Goal 2* | | | | | | | | | |
| 2.4 Develop Separation Algorithms | Δ Goal 1 | Δ Goal 2 | | | Δ Goal 3 | | | | | | | |
| 2.5 Assess Availability/Quality of Surveillance Data | | Δ Goals 1 & 2 | | | Δ Goal 3 | | | Δ Goal 4 | | | | |
| 2.6 Develop Safe and Efficient Terminal Airspace/Surface Operations | | Δ Goal 1 | | Δ Goal 2 | | | | Δ Goal 3 | | | | |

| CHALLENGES | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. Unmanned Aircraft | | | | | | | | | | | | |
| 3.1 State Awareness and Real-Time Mission Management | | | | Δ Goal 1 | | | | | | Δ Goal 2 | | |
| 3.2 Airframe Certification | | | | | | | | | | Δ Goals 1 & 2 | | Δ Goal 3 |
| 3.3 Precise Location and Navigation | TBD | | | | | | | | | | | |
| 3.4 UAS Avionics and Control Systems Certification | | | | | | | | Δ Goal 1 | | | Δ Goal 2 | Δ Goal 3 |
| 4. Human Systems Integration | | | | | | | | | | | | |
| 4.1 Display of Traffic/Airspace Information | | | | | | | Δ Goal 1 | | | | | |
| 4.2 Effective Human-Automation Interaction | | | | Δ Goal 1 | | | | Δ Goal 2 | | | | |
| 4.3 Pilot-Centric GCS | | | | | | | Δ Goal 1 | | | | | |
| 4.4 Definition of Roles and Responsibilities | | | | | | | Δ Goal 1 | | | | | |
| 4.5 Predictability and Contingency Management | | | | | | | Δ Goal 1 | | | | | |
| 4.6 System-Level Issues | | | | | | | Δ Goal 1 | | | | | |
| 4.7 NextGen Airspace Users and Providers – Qualification and Training | | | | | | Δ Goal 1 | | | | | | |
| 4.8 Support for Future/Enhance Capability of UAS | | | | Δ Goal 1 | | | | | | | | |

- Critical R&D Challenges mapped to FAA needs
- Planned UAS R&D coverage assessment for NAS integration goals
  - Human Systems Integration and Unmanned Aircraft need better coverage

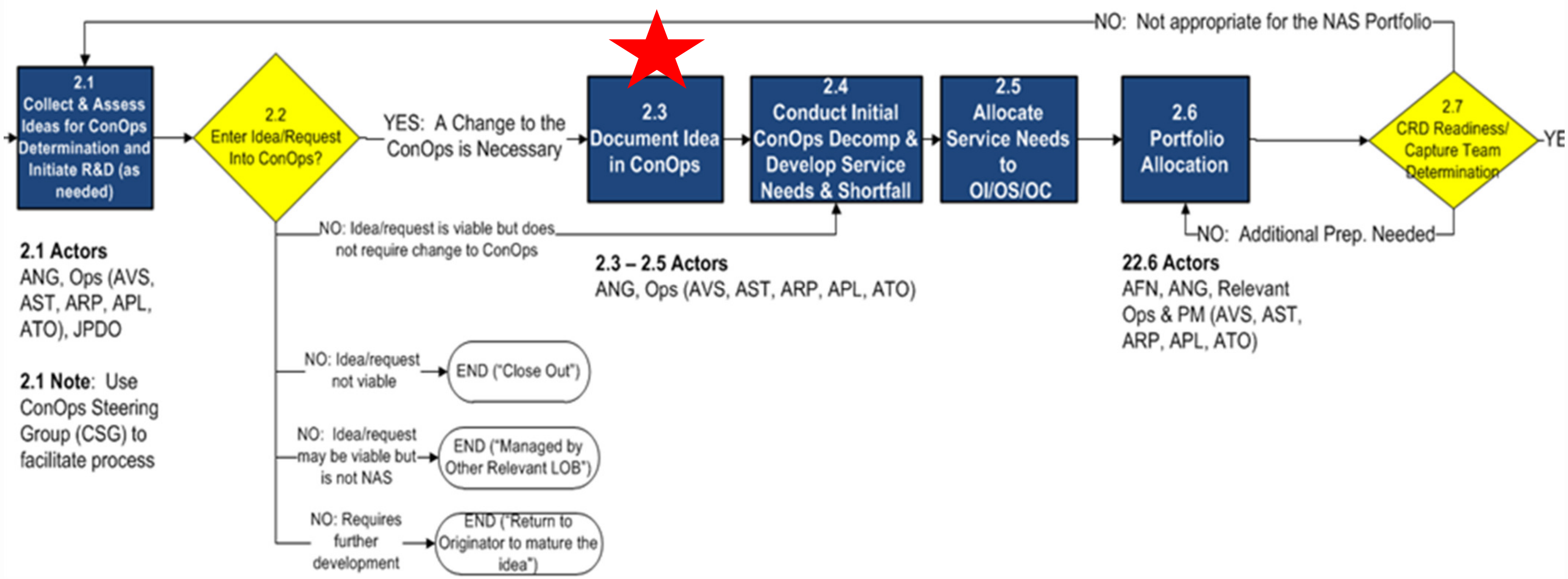
| Assessment of Level of Coverage Key: | |
|---|---|
| Coverage to be determined (TBD) | TBD |
| Strong or sufficient coverage | |
| Fair coverage | |
| Poor coverage or partial coverage | |

# UAS National Plan



# Next Steps: Idea to In-Service Implementation (i2i) Process

*Some UAS capabilities are in early stages of FAA's i2i process that manages solution trades for the NextGen portfolio in the most cost effective way*



# Stakeholders for UAS Integration

What might be the issues that stakeholders will consider for UAS integration?

- Researchers?
- FAA?
- Standards Organizations?
- Air Traffic Control?
- Manufacturers?
- Airlines or General Aviation?
- Others?

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# UAS Stakeholders

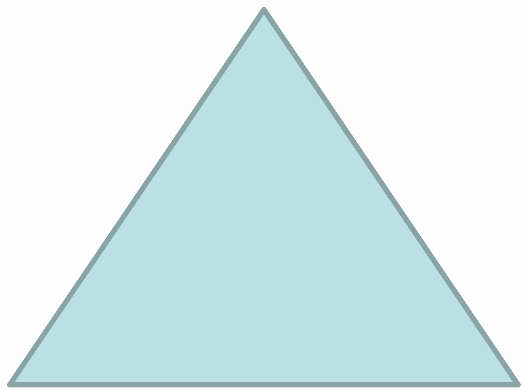

A high-level view of UAS Stakeholders and their associated roles/functions, which are categorized by the seven bins listed in the Key

◇ — **Policy/Regulatory**
☆ — **Research and Development**
△ — **Operators**
⬡ — **Operations**
⇨ — **Strategic**
○ — **NAS Community & Public Advocacy**
✚ — **Manufacturers**

# Balancing Competing Factors

## Safe Integration

*…new airframe certification…flight prioritization…pilot certification…lost link…autonomy…lower cost operations…*



## Security

*…policy to protect against intentional or unintentional disruptions…cybersecurity…*

## Privacy

*…the public perception (often not fact based)…"prying eyes" of UAS…local and Federal law…*

# Summary

- The Equity Concept
- Introduction to NextGen
- System Complexity and its Implications
- Trajectory-Based Operations
  - The TBO Concept
  - An Example: In-Trail Procedures
  - Another Example: Performance-Based Navigation
- Unmanned Aircraft Systems Integration